

## **Final Written Report for CleanPlanet Chemical**

### **I. Executive Summary**

CleanPlanet Chemical has been in the chemical recycling industry for the past 20 years. They manufacture and sell on-site chemical recycling equipment to aid other companies with their chemical waste management. As shown in the depictions below, the company cleans and recycles chemicals that are a byproduct of what manufacturers use for everything jobs like automobiles and heavy manufacturing. The AC 600/350 machines are about the size of a refrigerator and they are used to then clean and recycle the solvents. Otherwise, these companies would have to hire third party contractors to haul the used contaminated chemicals away and that process is not only expensive for the company, but often the chemicals are not recycled and create environmental issues going forward. Having the AC 600/350 machines allows the companies to recycle the chemicals for future use of their products. It saves costs for the company, is more efficient and in the long run, there are lasting benefits to the environment.

While CleanPlanet Chemical is a successful company and doing good in the world, there has been a recent problem involving their most successful solvent cleaning machines, the Always Clean 600/350. The machines require a microcontroller to operate the solvent cleaning system. CleanPlanet Chemical currently uses a RaspberryPi as the microcontroller and it is inefficient for the AlwaysClean 600/350. The inefficiencies lie in the frequency of the over the air updates. The company's lack of software engineers means that when software updates occur with the RaspberryPi, the machines have to be calibrated to handle the new updates. This forces the company to bring in experts to manually go into each machine to recalibrate it. This takes a lot of time and impedes on the daily functioning of the AC 600/350 which is the lifeline of the company. The client provided us with a list of technical requirements such as having ports for a display and keyboard, Over the air software updates with a long life cycle, Be operational to non-software engineers with simple coding language, Cost should be under \$1,000, 1 Analog IO (Input/Output) needed because MUX takes care of it, I2C Communication for Serial Data to be sent out to one multiplexer, and a RS232 port.

With the criteria in mind, we evaluated 3 microcontrollers that most matched the client's requirements and narrowed them down to the Siemens S7-1500, Schneider Electric Modicon M22, and Allen Bradley Micro 800. Based on weights that our client ranked on importance, Ease of use (35%), Degree of Freedom (30%), Software (25%), and Price (10%), we evaluated the three controllers on each of those criteria and

determined the Siemens S7-1500 scored the highest total out of the other options and therefore should be the microcontroller that CleanPlanet Chemical goes with.

## II. Company Summary

CleanPlanet Chemical has been in the chemical recycling industry for the past 20 years. They manufacture and sell on-site chemical recycling equipment to aid other companies with their chemical waste management. CleanPlant Chemical's machines allow the user to distill a variety of chemicals such as acetone. After the distilling process, the previously dirty chemicals are now ready to be used again. CleanPlanet Chemical not only helps their customers with cutting costs on chemical disposal but also creates a positive environmental impact.(Company Website) As shown in the depictions below, the company cleans and recycles chemicals that are a byproduct of what manufacturers use for everything jobs like automobiles and heavy manufacturing. The AC 600/350 machines are about the size of a refrigerator and they are used to then clean and recycle the solvents. Otherwise, these companies would have to hire third party contractors to haul the used contaminated chemicals away and that process is not only expensive for the company, but often the chemicals are not recycled and create environmental issues going forward. Having the AC 600/350 machines allows for the companies to recycle the chemicals for future use of their products. It saves costs for the company, is more efficient and in the long run, there are lasting benefits to the environment.

## III. Problem Statement

CleanPlanet Chemical has provided this team with the task of analyzing and recommending a new microcontroller for the AC350 & AC600 machines. The current microcontroller used for these industrial machines is the RaspberryPi 4 Model B. Physically, the RaspberryPi doesn't pose any problems to the proper performance of the AC350 & AC600. The problem comes from the operating system (OS) that is being used in the Raspberry Pi. This operating system gets frequent updates that will change how the machine works and sometimes even disable it. Providing a solution to this problem is of essential importance in order to decrease down time of the machines and decrease costs from emergency technician visits. The client criteria for the new microcontroller are as follows,

### Client Technical Requirements

- ports for a display and keyboard
- Over the air software updates with long life cycle
- Be operational to non-software engineers with simple coding language
- Cost should be under \$1,000.
- 1 Analog IO (Input/Output) needed because MUX takes care of it.
- I2C Communication for Serial Data to be sent out to one multiplexer.
- RS232 port.

#### IV. Client Requirements and Weighting Criteria needed

Our client wanted a weighting system in regards to picking the optimal programmable logic controller for the AC 600/350. In the client's view, having this sort of system will allow us to match their technical criteria with some functionality elements of the PLC. In doing this the client gave us their most important criteria and weighting. CleanPlanet Chemical Is the most important criteria for the PLC is Ease of use at (35%). The client wants Ease of use to be represented as The degree to which the PLC is designed to be user-friendly, accessible, and straightforward in its operation. The second most important criteria to the client was Degree of Freedom at (30%). The degree of freedom represents the degree to which the PLC offers versatile customization options and flexibility in design. The third most important criteria was Software at (25%). The client wants to make sure that the PLC has efficient programming tools with graphic capabilities, and robust debugging capabilities. Lastly, not as important but still need to be taken into consideration is Price at (10%). The price of the PLC should be reasonable and include upfront charges like for licensing. Please refer below for a visual of the weighting criteria.

Criteria	Description
Ease of use w = 35% (Most Important criteria of client)	The degree to which the PLC is designed to be user-friendly, accessible, and straightforward in its operation.
Degree of freedom w = 30% (Very Important)	The degree to which the PLC offers versatile customization options and flexibility in design.
Software w = 25% (High Priority for the client)	The degree to which the PLC has efficient programming tools with graphic capabilities, and robust debugging capabilities
Price w = 10% (Least Important criteria for client)	Upfront cost to have a working Programmable Logic Controller

Now that there is a weighting criteria that the client has, there now needs to be a rating system so that the client can know what rates each PLCs get based on the technical requirements and criteria weights. Our team and client decided that a rating

system from 1-5 in a points style would be the best way to go about rating. 5 would be the best because it would provide the highest points and at the end of the comparison of the PLC the microcontroller with the highest points is the most suitable for what CleanPlanet Chemical needs in their AC 600/350 machine.

Based on this data, our first criteria rating we will look at is the Ease of use at (35%). In order for a PLC to get a 5 in ease of use, the PLC programming should be picked up by anyone with minimal experience and effort. As a team, we understand that any new PLC would need at least some time to master, but a (5) means that there does not need to be any additional resources or external resources brought into the company. A (4) means that the programming will take a few weeks to master, but still will not need any outside costly resources to aid in this. A (3) is where there are challenges that arise with the PLC programming and will either require some advanced programming experience or some outside resources to come in. When it gets to a (2) this means that the PLC programming requires a lot of advanced programming knowledge, and costly external resources even to the point where those resources are limited to begin with. A (1) means that the PLC programming needs to be figured out and mastered by a specialist who would most likely need to be hired as an employee. A (1) in this category completely misses the criteria that the client expects and the PLC should not be pursued with this rating.

Our second criteria rating we will look at is the Degree of Freedom at (30%). A (5) in this category means that the PLC is customizable exactly to what the client needs. A (4) would mean that the PLC allows for a high level of customization and adaptability, but could still require some additional add on to match what the client wants. (3) is when there starts to be only a moderate amount of customization that the PLC has which could make it more challenging and costly for the client to use in the AC 600/350 system. A (2) means that the PLC has a use, but just not for what the client is looking for. It would be a mistake to go with this option. Finally a (1) means that third parties will have met the requirements so much so that there wouldn't be a need for that PLC anyway. A (1) and (2) would need to be avoidable in order to have satisfaction from the client.

Our third criteria rating we will look at is the Software at (25%). A (5) in this category means that the software components can be set up exactly to the needs of the client. (4) is also acceptable meaning that there is a high degree of programming capability. A (3) means that the software does have a moderate level of programming capability but could be challenging to meet some of the requirements of the client. A (2) means that the software is capable, but would not likely meet the requirements of the client. Lastly, a (1) means that the software will require major customizations from third parties or it cannot in fact meet the requirements of the client.

Finally, our last criteria rating will focus on the Price at (10%). This category is not as important for our client, but there are considerations that our client is looking for. A (5) would be the most ideal scenario where the new PLC would be at the same price as the current RaspberryPi which is at around \$50. It would be unlikely that different PLCs could meet this requirement, but still possible. A (4) which is much more likely means that the cost still meets the client's expectations being under the \$1000 cost requirement that the client set. Even a (3) is acceptable in this case for the client since it would still be around the \$1,000 requirement. A (2) is when there are costs starting to become over the client's goal of ~ \$1,000. Lastly, a (1) means that the PLC is going to cost several thousand dollars with licensing and other heavy costs associated with it. At a (1) it would not be financially feasible given that their current RaspberryPi is only ~\$50. Please refer below for a visual aid of the rating criteria.

Criteria	5	4	3	2	1
Ease of use w = 35% (Most Important criteria of client)	PLC programming can be picked up by anyone	PLC programming needs a few weeks to master	PLC programming is challenging but has available resources	PLC programming is challenging and has few available resources	PLC programming requires to hire a specialist
Degree of freedom w = 30% (Very Important)	PLC can be set up exactly to client's needs	PLC allows for a high level of customization and adaptability	PLC offers a moderate level of customization and adaptability	PLC still has a variety of use, but difficult to meet client's needs	PLC will need third parties to meet requirements
Software w = 25% (High Priority for the client)	Software can be set up exactly to client's needs	Software allows for a high level of programming capability	Software offers a moderate level of programming capability	Software is capable, but difficult to meet client's needs	Software will need third parties to meet requirements
Price w = 10% (Least Important criteria for client)	The cost is within the price of the Raspberry Pi (\$50~)	The cost meets client's under \$1000 cost requirement	The cost is around the \$1000 client requirement	The cost is well over the \$1000 client requirement by up to \$1000	The cost is expected to be several \$1000

## **V. Programmable Logic Controllers Technology Background**

### **Technology**

In the late 1960s the first Programmable Logic Controllers (PLCs) were developed. The goal to achieve with these controllers was to increase productivity and reliability when automating processes in an industrial environment. Factories started using PLCs in order to cut down on costs and increase quality by having machines do more precise and accurate tasks, thus, removing the risk of human error.

PLCs were designed with the industrial environment in mind, this means that apart from being able to optimize automation and take over repetitive tasks, PLCs are also extremely durable and capable of efficiently operating in hazardous conditions. The durability comes from the solid-state components within a PLC, solid-state components don't possess any moving parts. Having no moving parts essentially removes the need for maintenance due to wear and tear in a machine.

### **Components**

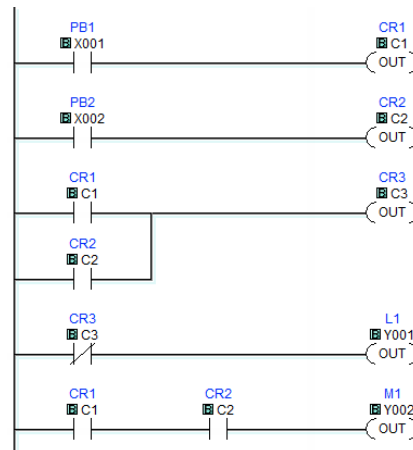
A Programmable Logic Controller, being a technological device, means it has multiple different components working together to achieve proper function. The most common components in a PLC are:

1. CPU: The CPU or central processing unit is the brains of the PLC. Similar to a standard computer, there needs to be a chip to take over all the processing required. Which type of CPU is utilized in the PLC is determined by how heavy the workload of the PLC will be.
2. Power Supply Unit (PSU): The PSU is the component responsible for adapting the voltage and current from the facility's power supply to the required power for the PLC. Under higher workload, the PLC will need high power and the PSU is the one that controls this aspect.
3. Input/Output (I/O): PLCs are categorized by the amount of Inputs and Outputs that it offers that could range from 30 I/Os all the way up to the thousands. The most popular I/Os are analog and digital. The inputs are the ones in charge of receiving any types of signals from sensors, buttons or other hardware or software to later send directions through the outputs to any machines or equipment based on feedback provided by the inputs.
4. Communication: The communication part of a PLC is composed of different types of ports such as usb, display, and ethernet that will provide ease of use to the owner. Whether it is for the programming part or for displaying information. Currently PLCs even have the capacity of wirelessly connecting to the internet without any types of add-ons.

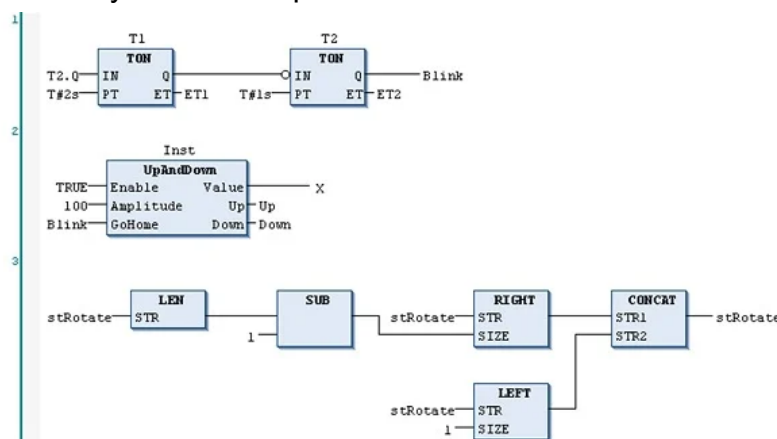
## Programming Methods

A PLC, similar to a computer, needs to be programmed to do a specific task. This is the first step that has to be done in order to ensure proper functioning in the long run. There currently are five different programming methods for a PLC, these are: ladder logic, structured text, sequential function charts, function blocks, and instruction lists. For this specific task with CleanPlanet Chemical, only two out of these five methods will be considered.

**Ladder Logic:** This was the first common method of programming a PLC. Even though it is the oldest method, it is still one of the most popular and widely used in the automation industry due to its simplicity. The reason this programming method obtained its name is due to its look where a series of conditions and actions are put together. This resembles an electrical diagram.



**Function Block Diagrams (FBD):** Another of the most popular methods for programming a PLC, FBD uses blocks that represent an action or process. Later, these blocks can be put together with other blocks to create a sequence that the PLC can follow in order to have any desired output.



## **PLC use within CleanPlanet Chemical**

CleanPlanet Chemical tasked this Technology Assessment team to research for a new industrial controller to adopt for their AC 350 & AC600 machine models. These two machines recycle solvent cleaners by using a distillation process. The main focus for the new PLC is to use it inside the machines and control all the recycle process instead of controlling a section of a factory. This opens up the potential for smaller PLCs to be used since less computing power is required.

## **Current Controller Used**

CleanPlanet Chemical is currently using a RaspberryPi 4 Model B to run the AC350 & AC600 solvent cleaning machines. A RaspberryPi provides computing power while at a great price point of ~\$60. The best aspects about this microcontroller are:

- Accessibility: These microcontrollers can be bought on websites like Amazon. This means that CleanPlanet Chemical will always have them accessible.
- Add-ons: The RaspberryPi is set up to be customizable, many different types of add-ons can be integrated in the microcontroller to tailor it to any type of use.
- Operating System Options: Since the RaspberryPi behaves like a computer, any type of operating system can be uploaded to it for operation. Windows, Linux, Raspbian, and other operating systems can be used to control the RaspberryPi.

## **Reason for new controller adoption**

Even though the RaspberryPi has impressive aspects, CleanPlanet Chemical has chosen to shift to an industrial controller due to the frequent software and hardware upgrade. The RaspBerryPi, being open for anyone to purchase, behaves like any other technology product that can be purchased online or in retail stores. There are constant software updates that affect CleanPlanet Chemical's code and the ability of the AC350 & AC600 machines to work. Additionally, hardware updates occur on a frequent basis where the device itself will change. This change in components also interferes with CleanPlanet Chemical's software. CleanPlanet Chemical is having trouble keeping up with all software, hardware, and firmware changes and this is the main reason why they are now exploring alternative options for their solvent cleaning machines.



## VI. Siemens, Allen-Bradley, and Schneider Microcontrollers

The technical requirements set by CleanPlanet Chemical were separated into the different criteria categories set by our team: Ease of use, Degree of freedom, Software and Price. How well the PLCs fit the requirements would determine their criteria rating for that category.

Technical Requirements	Criteria
Can be picked up by non-software engineers	Ease of use w = 35%
Long life cycle Ports for display and keyboard I2C communication I/O Ports for the MUX	Degree of freedom w = 30%
Over the air software updates	Software w = 25%
Price should be around \$1000	Price w = 10%

*Table: Relationship between the technical requirements and criteria*

### Siemens S7-1500:

- **Ease of use:** The Siemens PLC offers Ladder logic and Block Programming. Additionally, Siemens has extended software capabilities, and while great for the software criteria, they have sacrificed ease of use for software depth and abilities. Fortunately, they are aware of the steep learning curve and have extended technological customer support services. Criteria rating: 3
- **Degree of freedom:** The Siemens PLC has 1 ethernet port using PROFINET. PROFINET is a proprietary protocol belonging to Siemens that allows communication with other PLCs and Human Machine Interface (HMI). HMIs are any display with any human inputs. They can be touchscreens, switches, keyboards, etc. The S7-1500 has between 10 and 24 digital I/O and between 2 and 6 Analog I/O. It can function in the temperature range between -20 and +65 °C. It allows up to 32 plug-ins. Plug-ins are extensions that can easily be added on top of the PLC to allow additional capabilities. Criteria rating: 4
- **Software:** The Siemens portal is called the Totally Integrated Automation Portal (TIA) and allows for internet connection and code download to any PLC and code

upload from any machine in the world. The abilities of TIA are extensive and is the only environment that has a licensing fee. Criteria rating: 5

- **Price:** The S7-1500 is the most expensive of the three by far. With a base cost of \$1,550, Siemens prides itself in their build quality, and unfortunately it comes at a hefty price. Additionally, there is a \$450 one-time fee per license to gain access to their platform called the “Totally Integrated Automation” (TIA) portal. Criteria rating: 2

Technical Requirements	Criteria	PLC abilities	Criteria Rating
- Can be picked up by non-software engineers	Ease of use w = 35%	- Ladder Logic and Block Programming available - Sacrificed ease of use with depth - Heavy emphasis on technological customer support	3
- Long life cycle - Ports for display and keyboard - I2C communication - I/O Ports for the MUX	Degree of freedom w = 30%	- 1 ethernet port using PROFINET– HMI can be connected for display and keyboard - Digital I/O between 10 and 24 - Analog I/O between 2 and 6 - Operates between –20 and +65 °C - Allows up to 32 plug-ins	4
- Over the air software updates	Software w = 25%	- Totally Integrated Automation Portal (TIA) - Internet connection and code download	5
- Price should be around \$1000	Price w = 10%	- \$1,550 Market Price - TIA Portal requires licensing - \$450 One time fee - Is a high quality high price product	2

Table: Summary of the abilities of the S7-1500 from Siemens

### Allen Bradley Micro 800:

- **Ease of use:** The Allen Bradley PLC offers Ladder logic and Block Programming. Inversely to Siemens, the PLC’s software abilities are much easier to grasp and learn. Criteria rating: 5
- **Degree of freedom:** The Micro 800 has 1 USB 2.0 port, between 12 and 48 digital I/O and no Analog I/O. In order to reach the technical requirement as set by CleanPlanet Chemical about Analog I/O, an additional plug-in will have to be acquired. It can function in the temperature range between -20 and +65 °C. It allows up to 5 plug-ins. Criteria rating: 2
- **Software:** The Allen-Bradley portal is called the Connected Components Workbench (CCW). It is a much simpler version than the Siemens TIA so while it allows for an easier understanding of the program, there will be some limitations down the line. Mainly there have been complaints about CCW no longer working after certain Windows updates as well as issues importing outside libraries. Criteria rating: 1

- **Price:** The Market price for a Micro 800 is around \$450 but as stated in the Degree of Freedom criteria, an additional extension at \$250 is required for the Analog I/O port. The Software license is free. Therefore the total price for the Micro 800 is around \$700. Criteria rating: 4

Technical Requirements	Criteria	PLC abilities	Criteria Rating
- Can be picked up by non-software engineers	Ease of use w = 35%	- Sacrificed depth for ease of use - Ladder Logic and Block Programming available	5
- Long life cycle - Ports for display and keyboard - I2C communication - I/O Ports for the MUX	Degree of freedom w = 30%	- USB 2.0 port for keyboard and display - Digital I/O between 12 and 48 - No Analog I/O - Operates between -20 and +65 °C - Allows up to 5 plug-ins	2
- Over the air software updates	Software w = 25%	- Connected Components Workbench (CCW) - Complaints about CCW breaking after updates	1
- Price should be around \$1000	Price w = 10%	- Price around \$450 - Need to buy an additional plugin for analog at \$250 - Software License is free	4

*Table: Summary of the abilities of the Micro 800 from Allen-Bradley*

### Schneider Modicon M221:

- **Ease of use:** The Schneider PLC offers Ladder logic but no Block Programming. Similarly to Allan Brandley, the PLC's software abilities are much easier to grasp and learn. Criteria rating: 4
- **Degree of freedom:** The Modicon M221 has 1 ethernet port for HMI connection. It has between 16 and 32 digital I/O and 2 Analog I/O. It can function in the temperature range between -40 and +85 °C. It allows up to 14 plug-ins. Criteria rating: 3
- **Software:** Schneider's development environment is called the EcoStruxureMachine Expert. Similarly to CCW from Allen-Bradley, it has sacrificed complexity for ease of use. While it may be easier at the start, the legacy may become expensive. Criteria rating: 2
- **Price:** The Software license is free, and the market price for the base Modicon M221 is \$800. Criteria rating: 4

Technical Requirements	Criteria	PLC abilities	Criteria Rating
- Can be picked up by non-software engineers	Ease of use w = 35%	- Sacrificed depth for ease of use - Ladder Logic and but no Block Programming	4
- Long life cycle - Ports for display and keyboard - I2C communication - I/O Ports for the MUX	Degree of freedom w = 30%	- 1 ethernet port - Digital I/O between 16 and 32 - Analog I/O is at 2 - Operates between -40 and +85 °C - Up to 14 plug-ins	3
- Over the air software updates	Software w = 25%	- EcoStruxureMachine Expert - Barebones but free	2
- Price should be around \$1000	Price w = 10%	- ~\$800 - Licensing is free	4

Table: Summary of the abilities of the Modicon M221 from Schneider

## VII. Comparison

Compiling the final scores for each company results in the following table. The total score row was calculated by multiplying the criteria coefficient with their given score

E.g. Siemens Score calculation

$$Score_{Total} = 0.35 * 3 + 0.30 * 4 + 0.25 * 5 + 0.10 * 2 = 3.7$$

Criteria	Siemens S7-1500	Allen Bradley Micro800	Schneider Modicon
Ease of use w = 35%	3	5	4
Degree of freedom w = 30%	4	2	3
Software w = 25%	5	1	2
Price w = 10%	2	4	4
Total Score	3.7	3.0	3.2

Table: Decision matrix

Doing the calculation for all three companies, the one at the head of the pack is Siemens' S7-1500 PLC with a score of 3.7, 0.5 points in front of the second place. This difference is mostly due to Siemens' software abilities, with a score of 5, against Alan Bradley's and Schneider's, with a score of 1 and 2, respectively.

### **VIII. Final Recommendation**

Based on the results from the decision matrix, the final recommendation for CleanPlanet Chemical is the Siemens S7-1500 using the TIA portal.

### **IX. Risks and what needs to still be researched**

The main concern that could not be researched due to time constraints is how reliable CleanPlanet Chemical's in-house MUX is compatible with PLCs. While it is theoretically possible, getting it to work in the actual machine will require trial and error. The team would also have liked to have the time to experiment with the different graphical coding languages such as ladder logic and block programming in order to solidify our final recommendation.

Finally, it would have been great to test out the S7-1500 on the actual machine of CleanPlanet Chemical which is the AC600

### **X. Client Reaction**

The client was extremely pleased with our recommendation of the S7-1500 and is going to pursue this option for the microcontroller. Dr. Staats admired the fact that we came up with an in-depth criteria rating and weighting system that was simple to understand and the comparisons were clear between the competitors. The client also thought that our presentation had a real flow from the beginning with identifying the problem, to ultimately utilizing the criteria systems throughout the presentation. CleanPlanet Chemical will be using our presentation as a tool to start implementing the Siemens S7 1500.

## **XI. Appendix and Work Cited**

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